

**RESEARCH AND DEVELOPMENT OF SEPARATORS
FOR SILVER OXIDE-ZINC AND SILVER OXIDE-CADMIUM
CELLS FOR SPACECRAFT APPLICATION**

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**Third Quarterly Report
December 27, 1963 to March 27, 1964**

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PROJECT PERSONNEL

In carrying out the experimental work on this project at The Borden Chemical Company, the writers have been assisted by Dr. George Kitazawa, head of physical testing laboratory, by Mr. Richard Trickey, chemist, Mr. Gregory Cali, Mr. Harold Herring and Mr. Ronald Burton, assistants. In carrying out the sub-contract tests at Burgess Battery Company, Dr. Howard Strauss has the assistance of Mr. Frederick Poss, Mr. T. A. Carus, Jr., Mr. T. S. Hungate, Research Engineers.

I. INTRODUCTION

This is the third quarterly report covering work during the reporting period of December 27, 1963 - March 27, 1964 on Contract No. NAS 5-3467 which was awarded The Borden Chemical Company by the National Aeronautics and Space Administration, Goddard Space Flight Center, on June 27, 1963. The Burgess Battery Co. of Freeport, Illinois is participating in the contract in manufacturing and testing cells which incorporate separators developed for this study.

In the second quarterly report films from a large variety of polymeric materials were prepared and screened by bench scale procedures for suitability as membranes for silver oxide-zinc cells. Films showing acceptable properties were prepared in quantity and transmitted to Burgess for accelerated life tests in cells. This plan has been followed during the present period with particular emphasis on polymers and modified polymers resistant to oxidation by silver oxide. Tests at Burgess are continuing and will have been completed by the end of the next quarter with the exception of a few developed at the end of the present quarter.

II. SUMMARY

Although cycle life tests on experimental membranes are still in progress several different types have exceeded the life of cellophane or give indication of doing so.

Hydroxyethyl cellulose, polyvinyl alcohol and two of three variant hydroxyethyl polyvinyl alcohol types showed higher capacity than cellophane at the 50 amp discharge rate.

Membranes used in the test cells and related compositions were first screened and characterized by tests for conductivity, flexibility, tensile strength, tensile strength in 30% KOH, tensile strength after oxidation of 30% KOH saturated with Ag_2O , swelling in 30% KOH and 40% KOH. Data of the screening tests are presented. A number of candidates showed low electrical resistances of the order given by cellophane and stability to oxidation running from slightly better in the case of hydroxyethyl polyvinyl alcohols to much better in the case of some of the new candidates upon which life tests are at present unfinished.

III. FUTURE PROGRAM

1. The present contract calls for the construction of 50 cells based on the most promising separator developed. Since several of those under test qualify on the basis of cycle life, for further investigation it was decided in conference with the sponsor to use four different separator types to make up the 50 cells. Primary emphasis in the last quarter will be on the preparation of the separators and the assembly of the cells.

2. Selected membranes will be tested for silver migration by radioactive tracer technique.
3. Further synthetic modifications of suitable copolymers will be prepared for screening tests.

IV. EXPERIMENTAL SECTION

A. Oxidation of Films in 30% KOH saturated with Ag₂O

The apparatus for this test is pictured in Figure 12. A battery jar of 10" diameter x 10" depth was charged with 20 grams silver oxide (Ag₂O, Battery Grade, Ames Chemical Works) and 30% KOH (Fischer ACS) to a depth of 6 inches. The contents were stirred by a one inch Teflon-coated magnet bar at rapid rate by the supporting magnetic stirring motor (Fischer Thermix).

Films in replicates of 4 or 5 were precision cut in 15 mm widths x 7 to 8 inches and secured by masking tape to the insulated copper wires extending through the polystyrene plate. By adjustment of the wires the films were immersed to within one inch of the bottom of the jar. A set of PUDO cellophane strips was included in each test run of films as control; four to five sets of different films were compared with cellophane in each run. The closed apparatus was used in a constant temperature room and the internal temperature was found to remain constant at 23° C. within 0.5° C. The films after 72 hours immersion, were cut loose, blotted and tensile strength and elongation at break determined, immediately after blotting, on the Tinius Olsen Electromatic Universal Testing Machine. No attempt was made to measure the dimension of the swollen film, so that results described in the tables are expressed in lbs. per square inch of original dimension. In order to isolate the oxidation factor the same films were immersed in 30% KOH (without Ag₂O) for the same period and tested for tensile and elongation, the difference representing the effect of silver oxide.

Because of the widely varying rate at which individual film types oxidized it was necessary to check frequently against the possibility of depletion of the dissolved silver oxide. This was achieved by making use of the fact that cellophane is rapidly oxidized to a distinct brown color in 15 minutes by 30% KOH saturated with Ag₂O. At the first sign of decreased color intensity of a test cellophane strip 10 gram additional portions of silver oxide were added. Under the described test conditions the cellophane controls in nine test runs gave tensiles averaging 790 psi with standard deviation of 227. Tensiles on the cellophane control in 30% KOH only, averaged 3150 psi \pm 195. The design employed, which was simplified over more complicated designs involving filters to confine the solid Ag₂O, was relatively trouble-free. Although some contact of films with solid Ag₂O occurred, this was negligible as a consequence of the fact that excess silver oxide tended to lodge at the periphery out of direct contact with the suspended films.

A few experimental films oxidized even more rapidly than cellophane under the conditions, depleting the silver oxide at such a rate that it could not be resupplied by the stirring action. In such cases these films were removed from the system, and eliminated from further consideration.

B. Flex Tests

The Shopper Fold test proved to be too severe for many of the experimental films, some of which in the dry form were appreciably less flexible than materials like cellophane and polyvinyl alcohol. The MIT fold test at 1000 g tension placed all the experimental films on a graded scale and measurements were less erratic. (ASTM Folding Endurance of Paper D 643-43).

C. Electrical Conductivity Test

The conductivity cell was essentially a duplication of that described by Shair, Bruins and Gregor¹ and was pictured in our first quarterly report. The values in the tables for the films tested are given as the resistance of the films in ohms in this apparatus for an exposed diameter of .201 inches. This was determined after 3 days equilibration in 30% KOH or 40% KOH respectively. The resistance of three film samples each was calculated by subtracting the resistance of the cell determined the same day from the average resistance found for the three samples. In our equipment cellophane showed zero resistance in 30% KOH and 40% KOH. The cell was instrumented with a General Electric 650 A impedance bridge and cathode ray oscilloscope to indicate null point.

D. Electrolyte Absorption Test

Two-inch square sections of films were immersed in a thin layer of 30% KOH and 40% KOH contained in Petri dishes provided with a polyethylene gasket and covered with plates. The films were periodically removed, carefully blotted dry at the surface and rapidly weighed on an automatic Mettler balance. The films were then returned to the dishes for the next soaking period. This was continued to constant weight for at least 24 hours. The equilibrium levels were determined from weight-time plots.

E. Cell Construction Used at Burgess

The design of test cells is detailed below.

GENERAL DESIGN PARAMETERS
SS-5.5 Ag₂O-Zn Cell

Number of Ag ₂ O plates	6
Number of Zn plates	7
Weight of Ag ₂ O/plate	6.9 gm.
Weight of Zn/plate	3.2 gm.
Size of Ag ₂ O plate	1.75 x 2.125 x 0.028 in.
Size of Zn plate	1.75 x 2.125 x 0.030 in.
Theoretical Capacity of Cathode	9.60 a.h.
Theoretical Capacity of Anode	18.45 a.h.
Separator	1 layer/plate side 0.002 in. Aldex No. 13
Diaphragm	Description of diaphragms follows

For details of the testing schedule see pages 4-7 of the First Quarterly Report.

V. DISCUSSION

A. Swelling of Films in Electrolytes

The polymeric media found most successful as films in this study are soluble in water but insoluble in 30% and/or 40% KOH. An analogy might be made to monomeric molecules such as ethanol which is soluble in water and in 30% KOH but insoluble in 40% KOH, or isopropanol which is soluble in water but insoluble in both 30% and 40% KOH. The polymers must contain polar groups with polarity low enough to prevent dissolution with the concentrated alkali medium, yet high enough to imbibe concentrated alkali into the polymer phase. This electrolyte absorption by the film is essential to attaining its electrical conductivity, as pointed out in the previous report. The degree of swelling is also important from the standpoint of the space occupied by the separator in the assembled cell.

The Electrolyte Absorption test, as described under Experimental Section, was used to eliminate some of the films because of solubility in alkali. Films which reached a constant weight on equilibration with electrolyte were considered to be insoluble in the electrolyte. On the other hand, initial weight increase followed by a decline was considered evidence of eventual loss of polymer by solubility. Films which showed such eventual loss in weight were judged unsuitable for tests in cells. Examples may be found among some of the methyl cellulose modifications of Figure 3.

Those films which reached a constant weight level on equilibration maintained constant electrical conductivity, within the precision of the measurement, over a 26 day period, as shown in Table VII.

The electrolyte absorption tests have also provided useful data on the increase in thickness of the film in electrolyte. This is difficult to measure directly with calipers with any degree of precision on a film of say 1 mil thickness, not only because of the small values involved but because of the softening of the film which introduces the possibility of compressing it as it is calipered. In attempting to measure the dimensional changes in films at equilibrium with electrolyte it was noted last quarter that changes in length and width were small or compensating, the predominant change being in thickness. This was observed also by workers at Electric Storage Battery Co. (2). Since 30% and 40% KOH are of the order of specific gravity as most of the films of these experiments it is possible to equate the weight change to thickness change. Although this is an approximation it is believed to be more accurate than the direct measurement by calipers of swelling. We have accordingly used this calculation in Table VIII in comparing the thickness of the separator wraps in the assembled cell.

B. Oxidation of Films in 30% KOH Saturated with Ag_2O

This test was designed to simulate conditions in a zinc-silver oxide cell with respect to oxidation since it has been generally accepted that failure of cellophane membranes occurs at least in part by oxidation by the dissolved silver oxide. The work to date has been confined to 30% KOH which dissolves Ag_2O to the extent of .005% at room temperature. It should be noted also that AgO is also present during the first part of the discharge cycle and is a stronger oxidizing agent, although its solubility as such is reported to be very low (4).

For convenience we have equated stability in silver oxide oxidation to percentage retention in strength of the oxidized films. Since all conductive films are plasticized by the absorbed electrolyte each film under oxidation test was concurrently soaked in 30% KOH as a control and the tensile determined, the difference in tensiles representing the effect of Ag_2O on the plasticized film. Results are shown in Tables I-VI, and, graphically on typical films in Figure 14. By this comparison of KOH-plasticized film with oxidized film it is readily apparent that cellophane underwent the greatest deterioration on oxidation (to 15% of the original plasticized value), followed by HEPVA 374-59 and 60 (to 26% of the original plasticized value), followed by Polyvinyl alcohol (to 76% of the original plasticized value).

Methyl Cellulose and modified methyl cellulose of the current study were all markedly less degraded, the lowering in tensile being generally only to 90 to 100% of the original plasticized value. Visually, films of this class were only slightly discolored, remaining transparent.

Some speculation on these comparison seems justified. The greater deterioration of cellophane and the HEPVAs compared to polyvinyl alcohol and methyl cellulose (5) suggests that primary hydroxyl groups are more susceptible to oxidation than secondary hydroxyl. The anomalous lower degradation of HEPVA 79 in comparison to the other HEPVAs (see Figure 14) is

under analytical investigation.

The effect of silver oxide oxidation on electrical conductivity was also followed as shown in the last column of Table VII. There was a tendency towards lower resistance values after oxidation but the changes were within normal experimental variation.

C. Electrical Conductivity of Candidate Films

Performance of a separator in 30% KOH has been the principal target of our work to date. Among cellulose derivatives, methyl cellulose of about ds 1.8 (degree of substitution) does not absorb much electrolyte and offers too great a resistance to be satisfactory as a separator, as confirmed by test cells at Burgess. Hydroxyethyl cellulose of molecular substitution of 2.0 as another example, is soluble in 30% KOH, that is, too polar. This suggested that functional modifications in either structure or related structures could lead to gradation in conductivity of the modified film. In the present quarter systematic modifications of methyl cellulose were carried out. The effects on physical, chemical and electrical properties of the resulting films are summarized in Tables I to VI. From these tests candidates were selected, and prepared in sufficient quantity for the construction of cells at Burgess.

D. Burgess Tests

A summary of the status on March 31 of the life cycle tests on cells constructed with experimental separators is presented in Table VIII. In Tables IX, X and XI the history of the defunct cells is presented. This is given graphically in Figures 15, 16 and 17. In Table XII an abbreviated history of the diaphragms tested is given which gives a picture of the performance of the different assemblies at different discharge rates. It will be noted that HEPVAs 374-59, 374-60, the polyvinyl alcohol films and the hydroxyethyl cellulose film permitted higher capacity at the 50 amp discharge rate than did the cellophanes and other films.

It was intended that membranes in the test cells would be tested on the basis of comparative swollen thickness of the separator wraps (AxBxC of Table VIII). This was not uniformly adhered to in all cases. The fact that only single cells were tested in some cases should also be taken into consideration. Furthermore, although the practical aspects of cell construction justify a comparison on the basis of the same swollen thickness of the wrap there is no basis for predicting at the present state of our knowledge, for example, what quantitative effect the greater swollen thickness of the PValc of construction XI vs that of construction XII would have on the lives of the two sets. The results given and to follow should be considered therefore as a first round, calling for replicate testing, which will be possible with the fifty cells to be constructed on selected membranes.

Typical discharge curves for cellophane, HEPVA 374-60, and Methyl Cellulose 389-104 are given in Figures 18, 19, and 20.

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- (1) Shair et al, I. and E. Chem. 48 381-5
- (2) Oberholzer et al. Third Quarterly Report to NASA. Goddard Space Flight Center Covering Alkaline Battery Separator Study Dec. 28, 1962-March 28, 1963. Contract NAS-5-2860.
- (3) Rhyno. Silver Oxide-Zinc Battery Program. WADD Technical Report 61-36. Delco Remy Division of General Motors Corp. Contract No. AF 33(600)-41600.
- (4) Ruetschi et al. Third Quarterly Report. Investigation of AgO Primary Batteries Dec. 1, 1959-Feb. 29, 1960 Contract No. D.A.-36-039-SC-78318, Electric Storage Battery Company.
- (5) Ott. High Polymers V. p. 681. Interscience NYC 1954.

TABLE I. Properties of Films from Methyl Cellulose
Modifications Type B

	Untreated Methyl Cellulose	B1	B2	B3	B4	B5	PUDO Cellophane
Tensile 50% RH psi	10,100	10,150	5030	4660	4820	4110	17,330
Extension at Break %	33	11	7	5	8	2	28
Flex Test MIT (a) 50% RH cycles	3,065	2234	887	308	-	-	>10,000
Tensile - 72 hours							
in KOH (30%) psi	6,400	4260	2776	2490	1598	1087	3130 (c)
Extension at break %	36	31	43	39	46	60	12
in Ag ₂ O-KOH psi	5,810	4640	3030	2163	1565	766	457 (c)
Extension at break %	28	32	40	38	32	48	13
Absorbed Final Wt/Orig.Wt.							
30% KOH	1.12	1.55	1.60	1.97	2.08	2.66	2.92
40% KOH	1.12	1.50	1.63	1.89	1.97	2.22	2.59
Resistance (b) of Films - ohms							
in 30% KOH	21	2.7	3.5	1.5	0.9	3.4	0
in 40% KOH	507	43.7	9.5	3.5	6.9	4.4	0
Under Test at Burgess		x	x	x			

- Notes: (a) 1 kg. tension on film.
 (b) In conductivity cell with .20 in. diam. opening calcd. from
 (Resistance of cell + membrane - resistance of cell)
 (c) Analytical Test PT 370

TABLE II - Properties of Films from Methyl Cellulose
Modifications Type C

		Untreated Methyl Cellulose	C1	C2	C3	C4	C5
Tensile 50% RH	psi	10,100	11,280	12,800	5911	4304	3847
(Extension at Break)	%	33	10	18	6	3	2
Flox Test MIT (a) 50% RH cycles		3065	1837	1091	578	217	-
Tensile - 72 Hours							
in 30% KOH	psi	6400	6550	3120	2550	728	861
(Extension at Break)	%	36	37	41	46	43	60
in Ag O-KOH	psi	5810	6355	3360	1859	748	840
(Extension at Break)	%	24	26	39	30	37	48
Absorbed Final Wt/Orig.Wt.							
30% KOH		1.12	1.40	1.53	1.59	1.58	2.00
40% KOH		1.12	1.38	1.65	1.69	2.05	2.29
Resistance (b) of Films ohms							
in 30% KOH		21	4.1	0	0	0.9	0.9
in 40% KOH		502	34.1	0	3.5	0.4	3.5
Under Test at Burgess			x	x	x		

Notes: (a) 1 kg. tension on film
(b) In conductivity cell with .20 in diameter opening calcd. from
resistance of cell + membrane - resistance of cell.

TABLE III - Properties of Films from Methyl Cellulose
Modifications Type E

		Methyl Cellulose	E1	E2	E3	E4
Tensile 50% RH	psi	10,100	10,330	9720	11,120	8680
(Extension at Break)	%	33	22	16	29	28
Flex Test MIT (a) 50% RH cycles		3065	10,000	-	8073	3131
Tensile 72 hours						
in KOH (30%)	psi	6400	-	5420	5860	1090
(Extension at Break)	%	36	-	30	51	25
in Ag ₂ O-KOH	psi	5810	-	6440	5320	996
(Extension at Break)	%	24	-	44	45	18
Absorbed Final Wt./Orig. Wt.						
in 30% KOH		1.12	1.39	1.47	1.51	1.93
in 40% KOH		1.12	1.31	1.35	1.55	1.57
Resistance of Film (b) ohms						
in 30% KOH		21	11.1	8.0	5.0	0.3
in 40% KOH		507	41.3	37.8	25.5	0
Under Test at Burgess					x	x

Notes: (a) 1 Kg. tension on film
(b) In conductivity cell with 0.20 diam. opening.

TABLE IV. Properties of Films from Methyl Cellulose
Modification Type D

		Untreated Methyl Cellulose	D1	D2	D3	D4
Tensile 50% RH	psi	10,100	9390	8610	7430	7700
(Extension at Break)	%	33	17	21	7	12
Flex Test MIT (a) 50% RH cycles		3,065	3457	3017	2443	1539
Tensile 72 hours						
in 30% KOH	psi	6400	5250	3070	5535	3916
(Extension at Break)	%	36	26	139	-	-
in Ag ₂ O-KOH	psi	5810	4290	2880	1960	1014
(Extension at Break)	%	24	26	21	31	26
Absorbed Final Wt/Orig.Wt.						
in 30% KOH		1.12	1.32	1.37	1.49	1.66
in 40% KOH		1.12	1.22	1.33	1.47	1.54
Resistance (b) of Film -ohms						
in 30% KOH		21	5.4	1.4	0	0
in 40% KOH		502	33.3	4.2	0.5	1.8

Notes: (a) 1 Kg. tension on film
(b) In conductivity cell with 0.20 diam. opening.

TABLE V. Properties of Films From Methyl Cellulose
Modifications Type A

		Untreated Methyl Cellulose	A1	A2	A3	A4
Tensile 50% RH	psi	10,100	7430	6090	5360	3876
(Extension at Break)	%	33	21	14	14	
Flex Test MIT 50% RH	cycles	3065	332	576	106	18
Tensile 72 hours						
in 30% KOH	psi	6400	4860	4110	2710	-
(Extension at Break)	%	36	28	31	22	-
in Ag ₂ O-KOH	psi	5810	4000	4600	(c)	(c)
(Extension at Break)	%	24	21	27	21	-
Absorbed Final Wt./Orig. Wt.						
30% KOH		1.12	1.41	1.49	1.43	1.53
40% KOH		1.12	1.22	1.44	1.46	1.46
Resistance	ohms					
in 30% KOH		21	11.3	10.1	3.4	2.1
in 40% KOH		507	121	80.9	53.6	50.6
Under Test at Burgess			x			

Notes: (a) 1 Kg tension on film
(b) In conductivity cell with 0.20 diam. opening
(c) Ag₂O was quickly exhausted in presence of these films;
evidence of solution of PEI.

TABLE VI. Properties of Films from HEPVA, PValc and Hydroxyethyl Cellulose

		HEPVA 374-59 High M.Wt.	HEPVA 374-60 Low M. Wt.	HEPVA 79	PValc 421-39	Hydroxy- ethyl cel- lulose 389-121-2
Tensile 50% RH	psi	4960	5260	6380	7590	5250
(Extension at Break)	%	630	550	583	135	27
Flex Test MIT	cycles	stretches	stretches	stretches	10,000	720, stretch
Tensile 72 hours						
in 30% KOH	* psi	2470	1920	4920	4820	soluble
(Extension at Break)	%	760	635	800	540	-
in 45% KOH	* psi	632	469	1705	3670	soluble
(Extension at Break)	%	545	435	436	445	-
Absorbed Final Wt./Orig.Wt.						
30% KOH		1.56	1.65	1.47	1.90	soluble
40% KOH		1.56	1.57	1.79	2.38	1.65
Resistance of Film (b)						
in 30% KOH	ohms	0	0	0	0	soluble
in 40% KOH	ohms	0	0	0	0	0

Note: (b) In conductivity cell with 20" diam opening

* Comparative analytical test set PT 370 (Simultaneous tests in same solution of all the films in this table).

Table VII. Electrical Resistance of Membranes, Changes in 30% KOH and in 30% KOH Saturated with Ag₂O

Reference	Composition	(a)						Oxidized (Silvered) Film (After Ag ₂ O) 30%KOH Ohms
		3 Days in		26 Days in				
		30%KOH ohms	40%KOH ohms	30%KOH ohms	40%KOH ohms			
389-124	Methyl Cellulose	21.0	502.0					
421-35	Methyl Cell. Mod. B1	2.7	21.6	0.3	8.8	0.0		
421-7	" " B 2	2.6	5.8	0.0	1.9	0.0		
421-8	" " B 3	1.7	0.0	0.0	1.0	0.0		
421-9	" " B4	0.0	0.4	0.1	5.9	0.7		
421-10	" " B 5	0.0	1.5	0.0	0.1	1.2		
421-34	Methyl Cell. Mod. A 1	11.3	121.0	0.1(?)	49.0	7.2		
421-11	" " A 2	10.1	81.0	6.1	37.1	-		
421-12	" " A 3	3.4	53.6	8.2	25.6	4.2		
421-13	" " A 4	2.1	50.6	5.7	29.8	-		
421-36	Methyl Cell. Mod. C 1	2.9	21.0	1.9	9.5	0.0		
421-15	" " C 2	0.0	1.2	1.6	1.3	0.0		
421-16	" " C 3	0.0	3.4	0.4	1.4	0.0		
421-17	" " C 4	1.7	0.0	0.0	3.1	0.0		
421-18	" " C 5	0.0	0.4	0.0	2.8	0.2		
421-23-1	Methyl Cell. Mod. D 1	5.4	33.3	7.6	34.1	0.1		
421-24	" " D 2	3.2	11.3	1.5	16.5	0.1		
421-25	" " D 3	0.0	0.5	0.1	5.7	0.1		
421-26	" " D 4	0.0	0.5	0.2	0.0	0.1		
	Cellophane PUDO 193	0.0	0.0	0.0	0.0	0.0		
421-39	PVAlc	0.0	0.0	-	-	0		
374-59	Hydroxyethyl PVAlc	0.0	0.0	-	-	-		
79	Hydroxyethyl PVAlc	0.0	0.0	-	-	-		
389-121-2	Hydroxyethyl Cellulose	sol	0.0	-	-	-		
389-132	Methyl Cell. Mod. E 1	11.1	45.4	8.3	38.6	6.1		
389-127-2	" " E 2	8.0	37.8	6.5	27.2	5.9		
389-126-2	" " E 3	5.0	27.5	-	-	1.8		
389-140	" " E 4	0.3	2.1	-	-			

Notes: (a) Standard procedure for conductivity test.

TABLE VIII. Life Cycle Tests of Films in Batteries. Status 5/31/64

Con- Struc- tion Type	FILM	(a)	(b)	(c)	(a•b•c)	Capacity		Status
		Mils 50% RH	Swelling in Electrolyte Final wt/ Orig wt.	Layers Plate Side	Swollen Thick- ness Mils	A.H. on Latest cycle	Latest cycle	
VII	PUDO Cellophane	1.0	2.9	5	14.5	15	9.34	dead
		"	"	"	"	20	9.86	dead
		"	"	"	"	14	9.34	dead
		"	"	"	"	17	9.56	dead
XI	374-61 PValc	1.5	1.82	4	10.9	16	11.84	running
		"	"	"	"	16	11.94	running
XII	389-110 PValc	1.0	1.89	4	7.6	16	12.06	running
		"	"	"	"	16	11.90	running
XIII	389-104 Methyl Cellulose	1.4	1.11	6	9.3	6	6.56	stopped
XIV	389-121 Hydroxyethyl * Cellulose	1.3	1.65	5	10.7	16	11.36	running
VIII	79 HEPVA	1.5	1.48	6	13.2	28	6.96	running
		"	"	"	"	28	7.84	running
IX	374-59 HEPVA	1.7	1.56	6	15.9	23	9.44	running
		"	"	"	"	23	9.20	running
X	374-60 HEPVA	1.6	1.50	6	14.4	17	11.30	dead
		"	"	"	"	14	7.20	dead
<u>Methyl Cellulose Modifications</u>								
XVII	389-130 A 1-100	1.4	1.21	6	10.1	11	9.96	running
XIX	421-41 B-2	1.2	1.60	6	11.5	2	11.14	running
XVI	389-128 C-1	1.3	1.40	5	9.1	11	10.80	running
XV	389-126-2 E-3	1.4	1.51	6	12.7	11	11.36	running
XVIII	389-140 E-4	1.2	1.93	6	13.9	11	11.86	running

Note * In 40% KOH

TABLE IX. Cycling Data Construction Type VII
DuPont 193 PUDD Cellophane

Cycle No.	Dis-charge Rate Amp.	Time Output		Time Output		Time Output		Time Output	
		Hr.	A.H.	Hr.	A.H.	Hr.	A.H.	Hr.	A.H.
1	2	5.55	11.10	5.58	11.16	5.57	11.14	5.57	11.14
2	2	5.73	11.46	5.80	11.60	5.63	11.26	5.78	11.56
3	10	.97	9.70	1.05	10.50	.97	9.70	1.03	10.30
4	50	.10	5.00	.13	6.50	.10	5.00	.13	6.50
5	2	6.18	12.36	7.02	14.04	6.60	13.20	6.15	12.30
6	2	4.80	9.60	5.45	10.90	4.88	9.76	5.08	10.16
7	2	5.10	10.20	5.97	11.94	5.08	10.16	5.70	11.40
8	2	5.22	10.44	6.17	12.34	5.47	10.94	5.90	11.80
9	2	5.22	10.44	5.92	11.84	5.18	10.36	5.55	11.10
10	2	5.28	10.56	6.12	12.24	5.12	10.24	5.53	11.06
11	2	4.90	9.80	5.97	11.94	4.77	9.54	5.47	10.94
12	2	5.27	10.54	5.88	11.76	4.92	9.84	5.40	10.80
13	2	4.87	9.74	5.77	11.54	4.57	9.14	5.20	10.40
14	2	4.90	9.80	5.55	11.10	4.67	9.34	4.93	9.86
15	2	4.67	9.34	5.45	10.90	0.00	0.00	4.98	9.96
16	2	0.00	0.00	5.45	10.90			4.75	9.50
17	2			5.32	10.64			4.78	9.56
18	2			5.13	10.26			0.00	0.00
19	2			4.90	9.80				
20	2			4.93	9.86				
21	2			0.00	0.00				

TABLE X. Cycling Data - Construction Type X
Borden 374-60, Medium Molecular Weight HEPVA

Cycle No.	Discharge Rate Amp.	T I M E O U T P U T		T I M E O U T P U T	
		Hr.	A.H.	Hr.	A.H.
1	2	5.43	10.86	5.33	10.66
2	2	5.85	11.70	5.72	11.44
3	10	1.10	11.00	1.08	10.80
4	50	.20	10.00	.20	10.00
5	2	6.43	12.86	6.00	12.00
6	2	5.90	11.80	5.83	11.66
7	2	6.05	12.10	6.03	12.06
8	2	6.05	12.10	6.00	12.00
9	2	6.02	12.04	6.00	12.00
10	2	6.00	12.00	6.00	12.00
11	2	5.98	11.96	5.97	11.94
12	2	5.97	11.94	5.92	11.84
13	2	5.95	11.90	5.82	11.64
14	2	6.00	12.00	3.60	7.20
15	2	5.95	11.90	1.70	3.40
16	2	5.72	11.44		
17	2	5.65	11.30		
18	2	0.00	00.00		

TABLE XI. Cycling Data - Construction Type XIII
Borden 389-104, Methyl Cellulose 100

Cycle No.	Discharge Rate		Time Output	
	Rate	Amp.	Hr.	A.H.
1		2	2.87	5.74
2		2	2.63	5.26
3		10	.47	4.70
4		50	.05	2.50
5		2	3.05	6.10
6		2	3.28	6.56
7		2	2.85	5.70

TABLE XII. A.H. Capacity Readings During History of Test Cells (to 1.0 volt end point)

Cycle: Discharge Rate	1 C/5	3 C/1	4 C/0.2	5 C/5	10 C/5	15 C/5	Latest Cycle C/5 A.H.	
PUDO Cellophane	11.10	9.70	5.0	12.36	10.56	9.34	(16)	short
	11.16	10.50	6.5	14.04	12.24	10.90	(21)	short
	11.14	9.70	5.0	13.20	10.24	short	(15)	short
	11.14	10.30	6.5	12.30	11.06	9.96	(18)	short
374-59 HEPVA	10.84	11.20	10.0	12.70	11.70	10.86	(23)	9.44 running
	10.84	11.20	10.0	12.70	11.76	11.14	(23)	9.20 running
374-60 HEPVA	10.86	11.00	10.0	12.86	12.00	11.90	(18)	short
	10.66	10.80	10.0	12.0	3.40	dead	(15)	dead
79 HEPVA	8.64	8.3	3.5	16.16	12.24	9.20	(28)	6.96 running
	8.74	8.2	2.5	16.96	12.24	9.50	(28)	7.84 running
	8.94	10.8	5.0	14.06	(9)short		(9)	short
374-61 PVALc	11.64	11.50	11.00	12.54	11.80	11.80	(16)	11.84 running
	11.64	11.50	11.00	12.44	11.80	11.90	(16)	11.94 running
389-110 PVALc	11.64	11.70	11.00	12.24	11.80	12.1	(16)	12.06 running
	11.60	12.00	11.00	12.46	11.76	11.9	(16)	11.09 running
389-104 Methyl Cell.	5.74	4.70	2.50	6.10	7.0	stopped, high resistance		
389-128 C-1	11.54	10.70	4.00	14.16	10.80		(11)	10.80 running
389-130 A-1	10.76	5.20	2.50	15.0	10.0		(11)	9.96 running
389-126-2 E3	10.94	9.70	3.5	14.80			(11)	11.36 running
389-140 E-4	10.94	9.50	3.5	14.10	11.9		(11)	11.86 running
389-121 HEC*	11.40	11.00	10.00	13.34	11.4		(16)	11.36 running

* In 40% KOH

Fig. 1 - Methyl Cellulose Modifications. B. Type

Films in 30% KOH

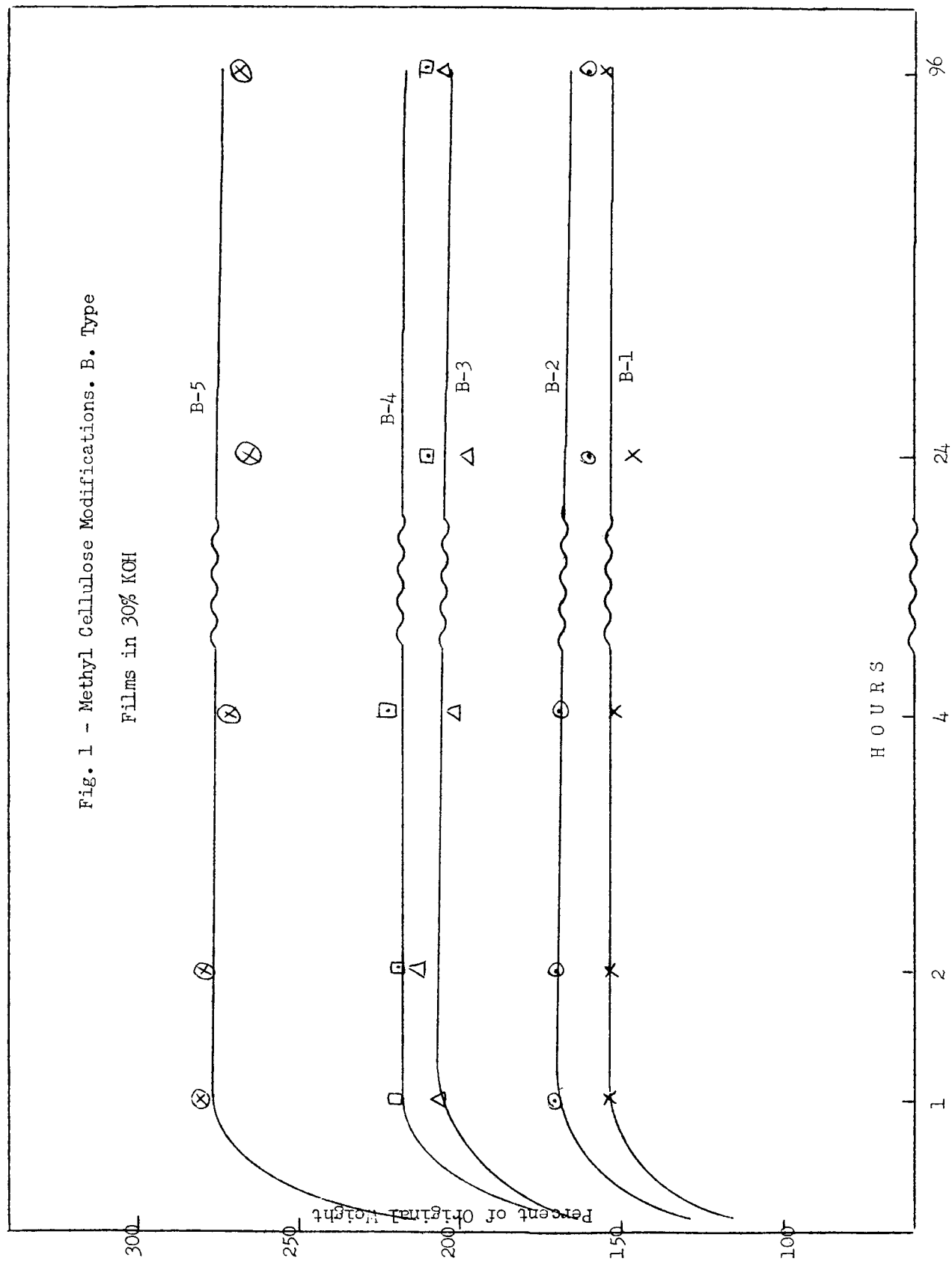


Fig. 2 Methyl Cellulose Modifications B Series
Films in 40% KOH

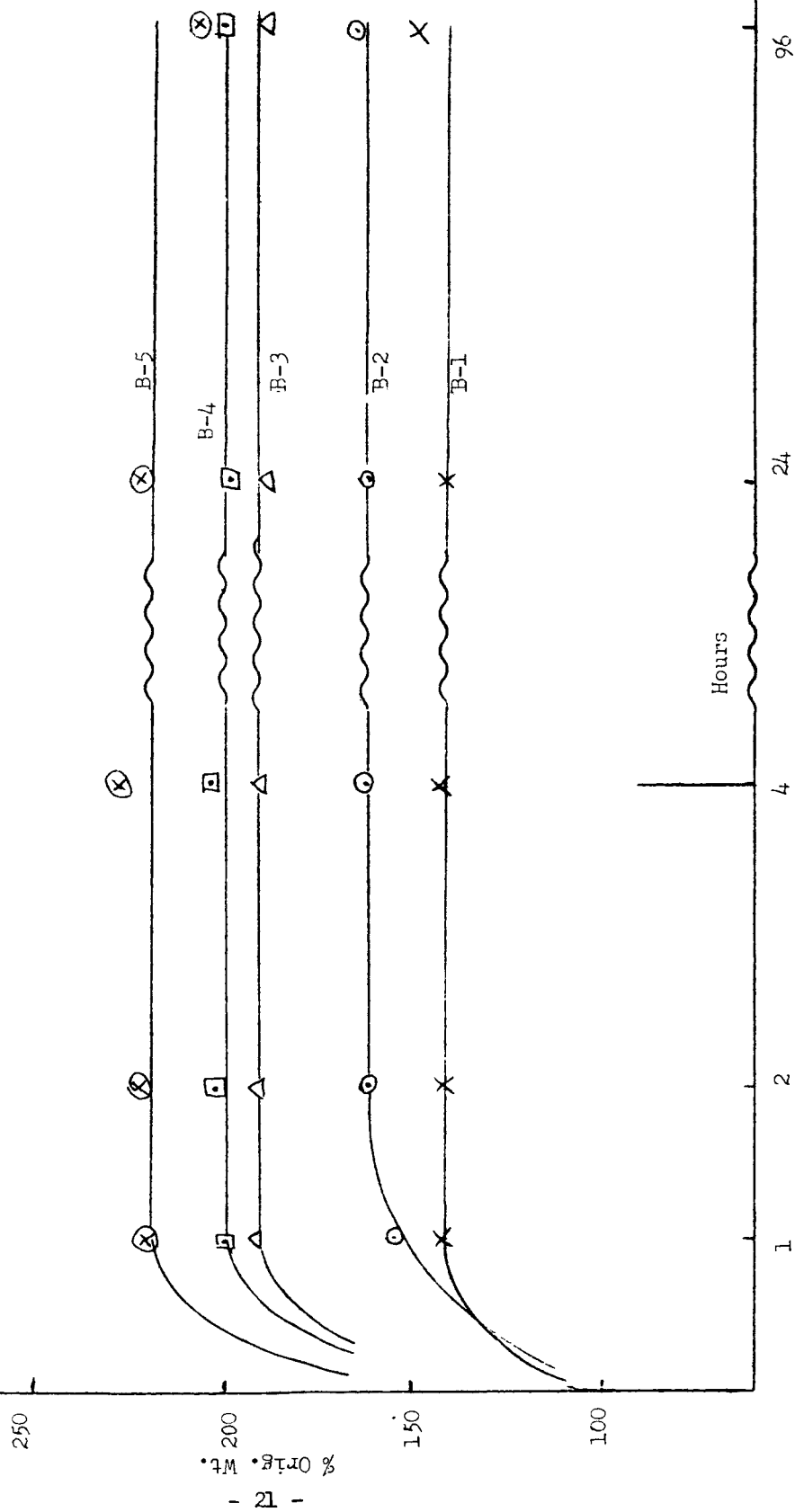


FIG. 3 Methyl Cellulose Modifications A Series
Films in 30% KOH

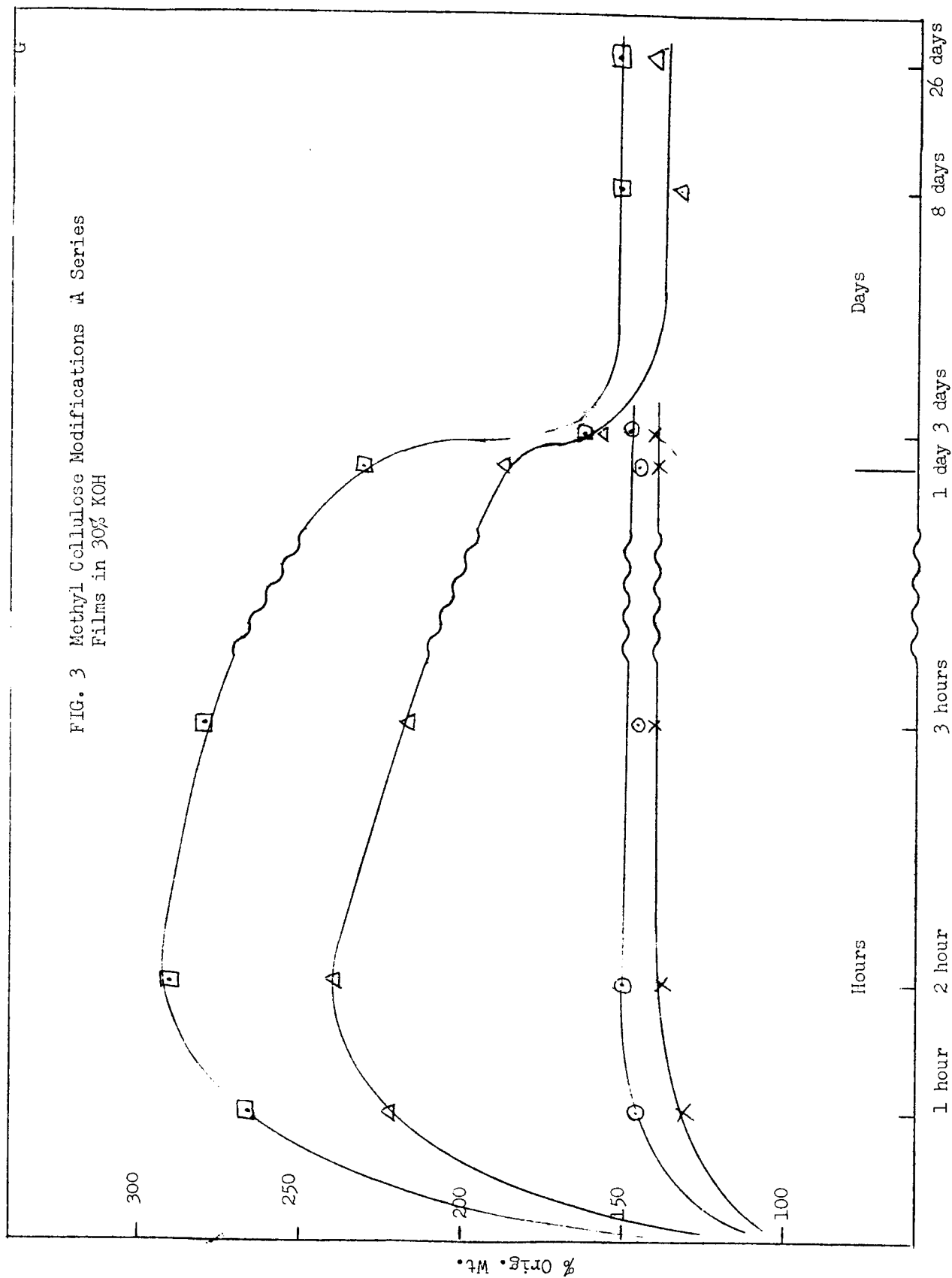


Figure 4 - Methyl Cellulose Modifications. A Type

Film in 40% KOH

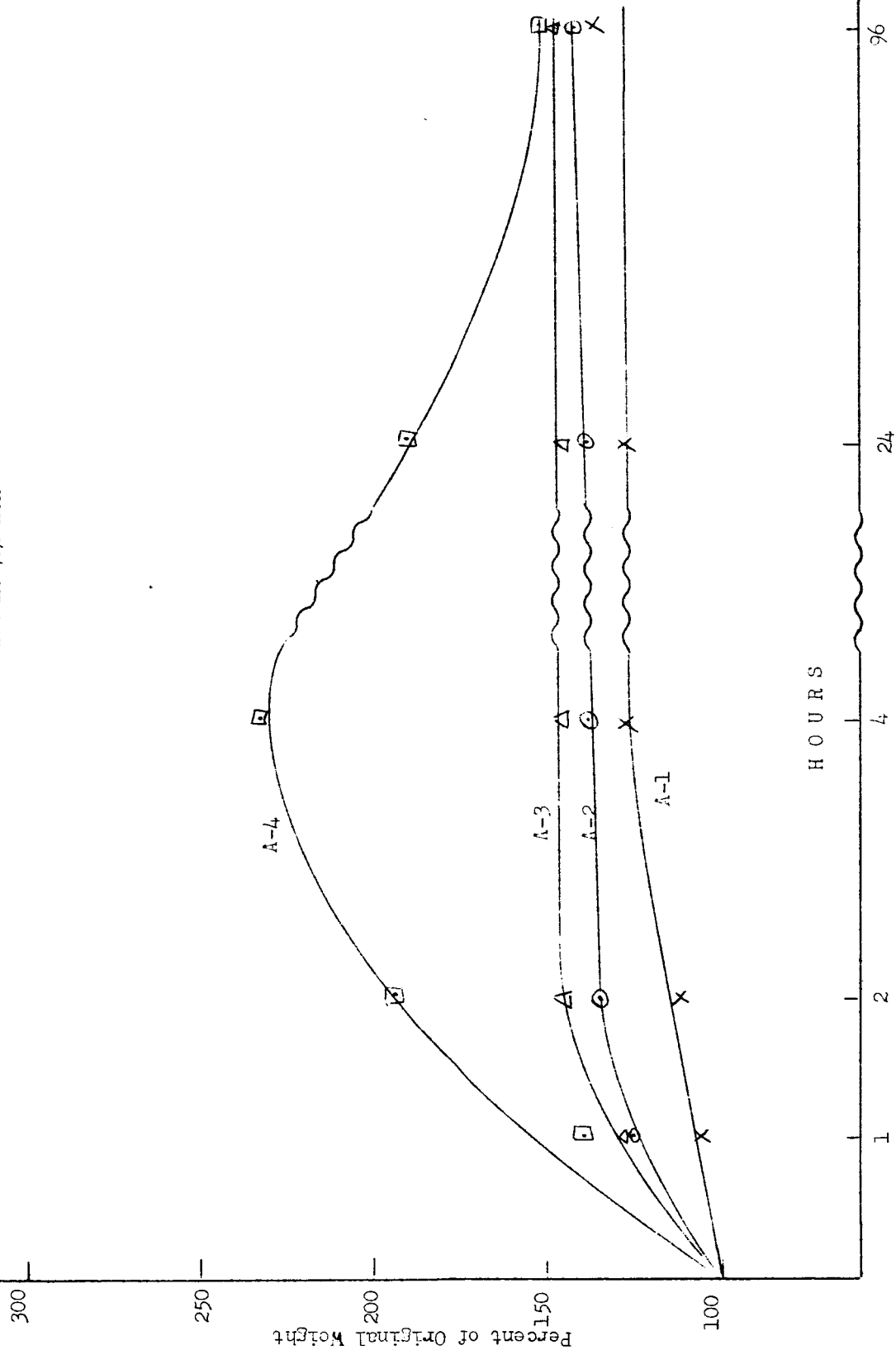


FIGURE 5 - Methyl Cellulose Modifications. C Type

Films in 30% KOH

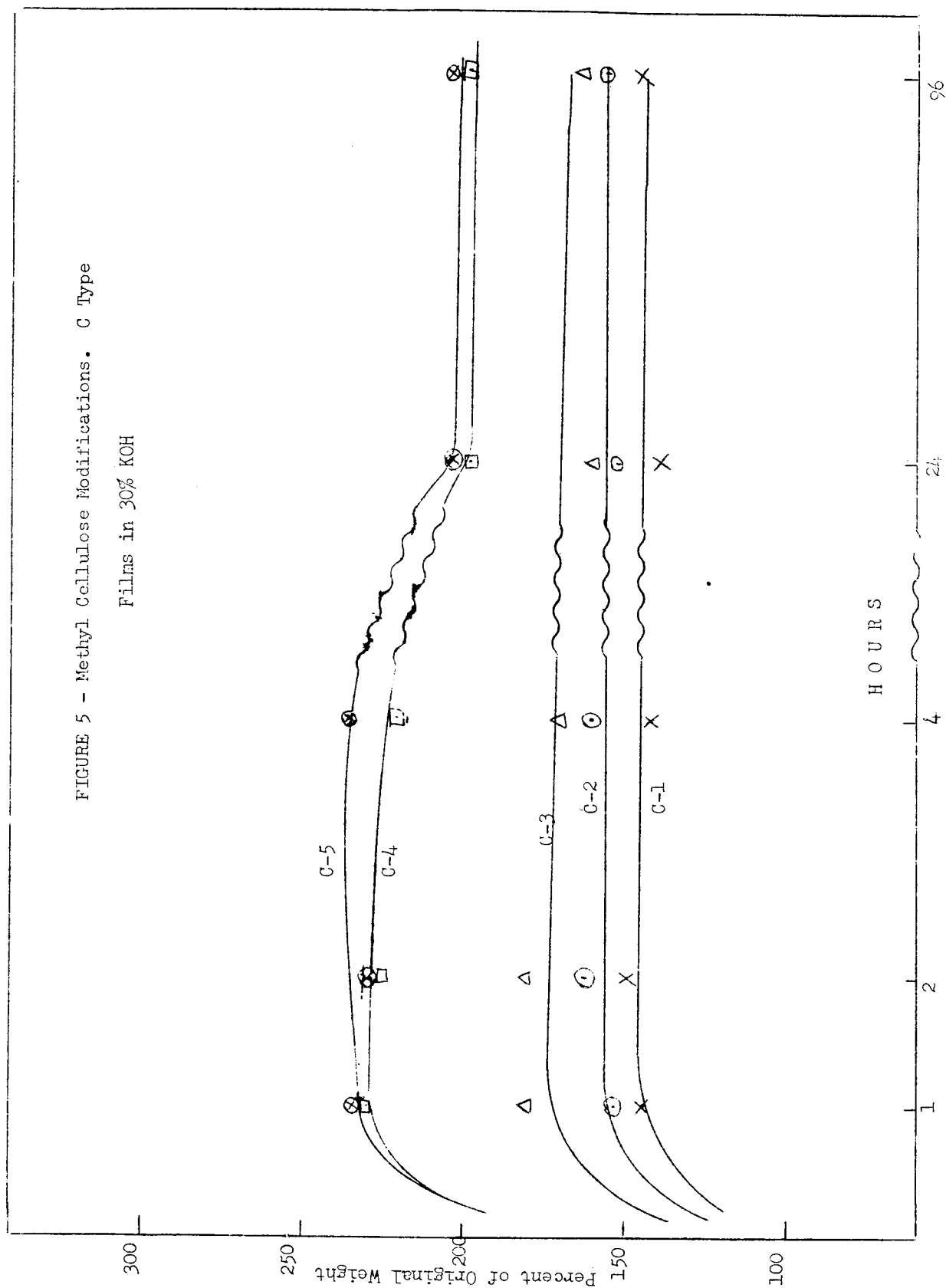


Figure 6 - Methyl Cellulose Modifications. C Type

Films in 40% KOH

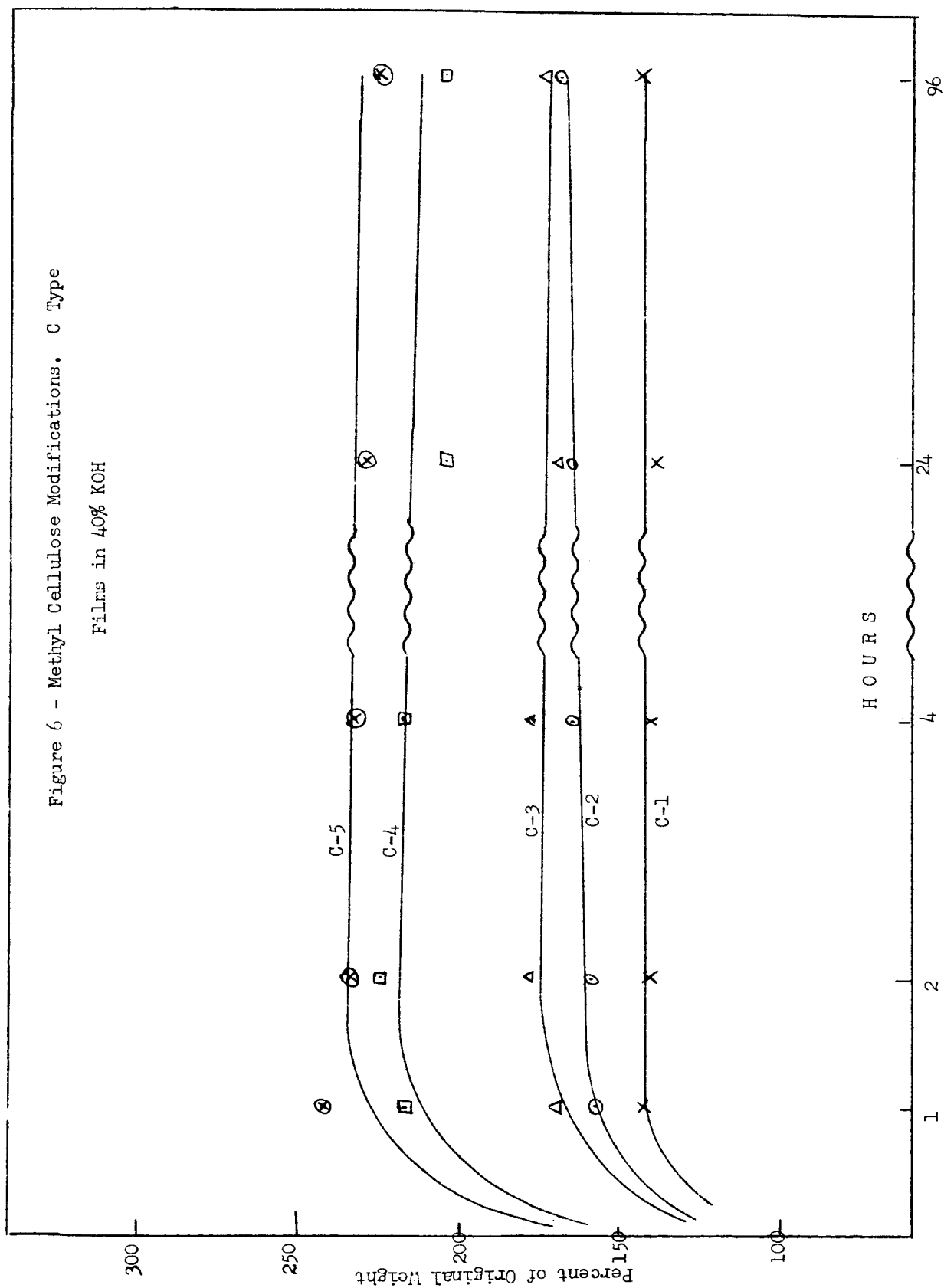


Figure 7 - Methyl Cellulose Modifications E Type

Films in 30% KOH

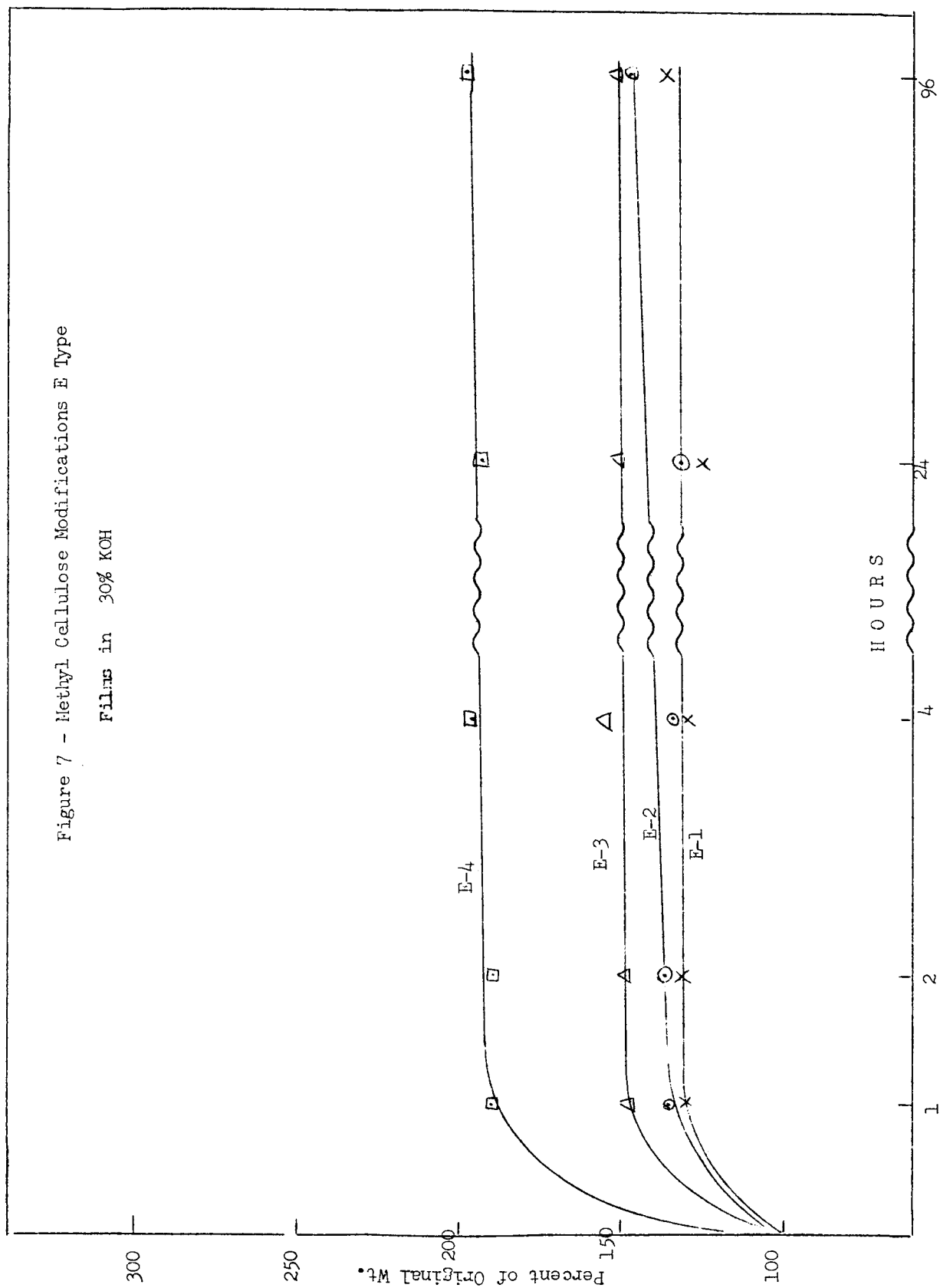


Figure 8 - Methyl Cellulose Modifications E Type

Films in 40% KOH

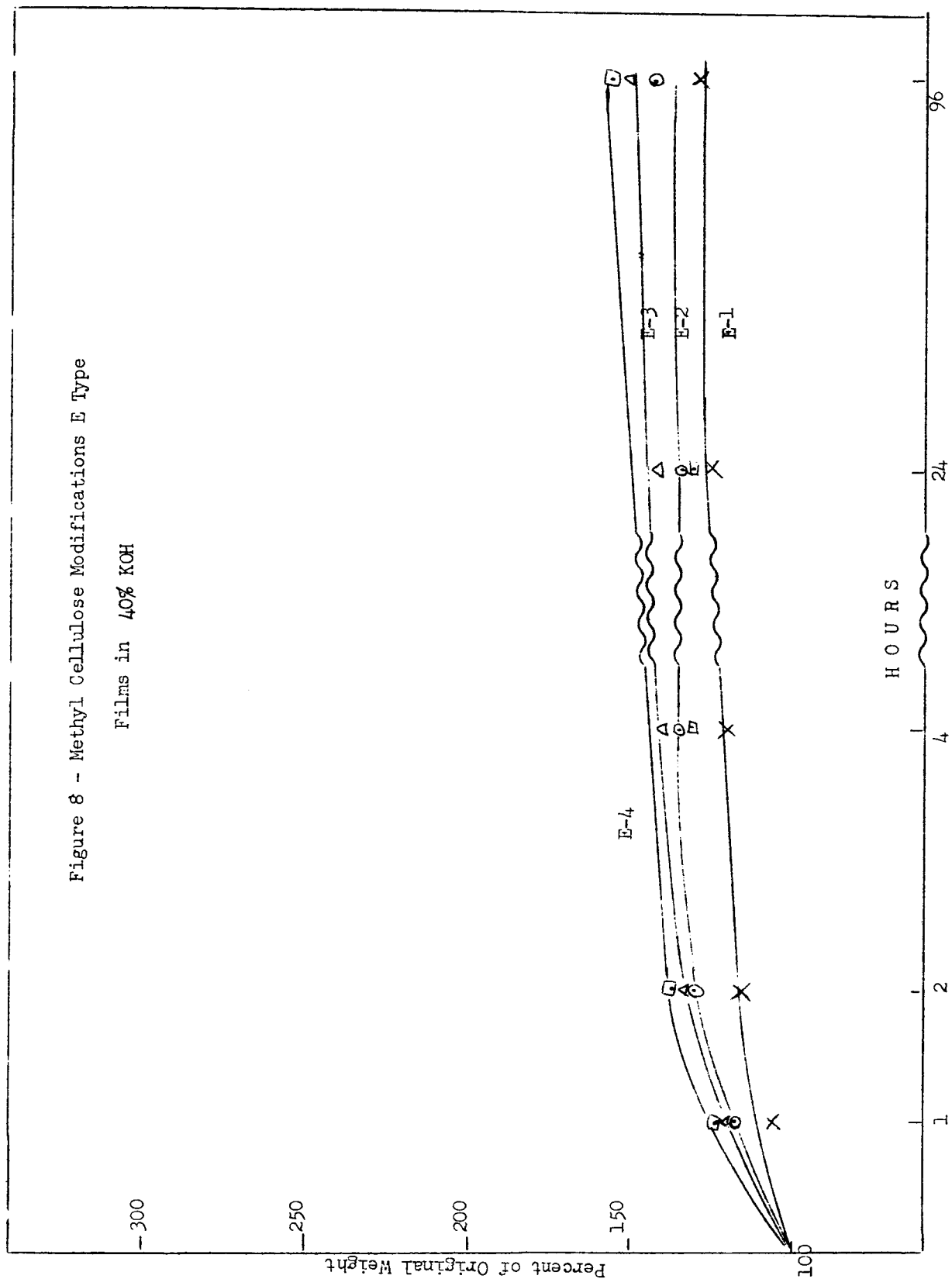


Figure 9 - Methyl Cellulose Modifications. D Type
Films in 30% KOH

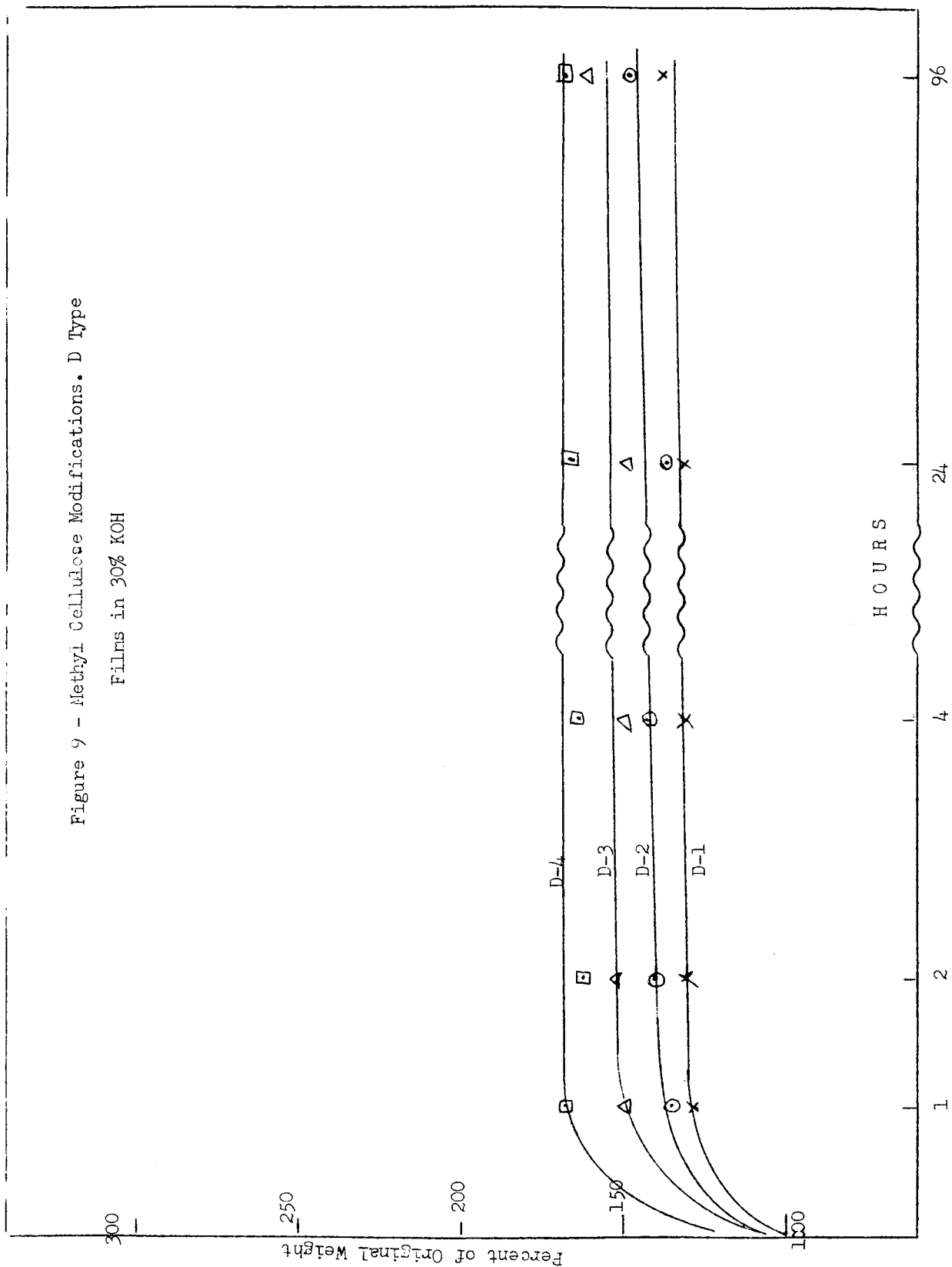
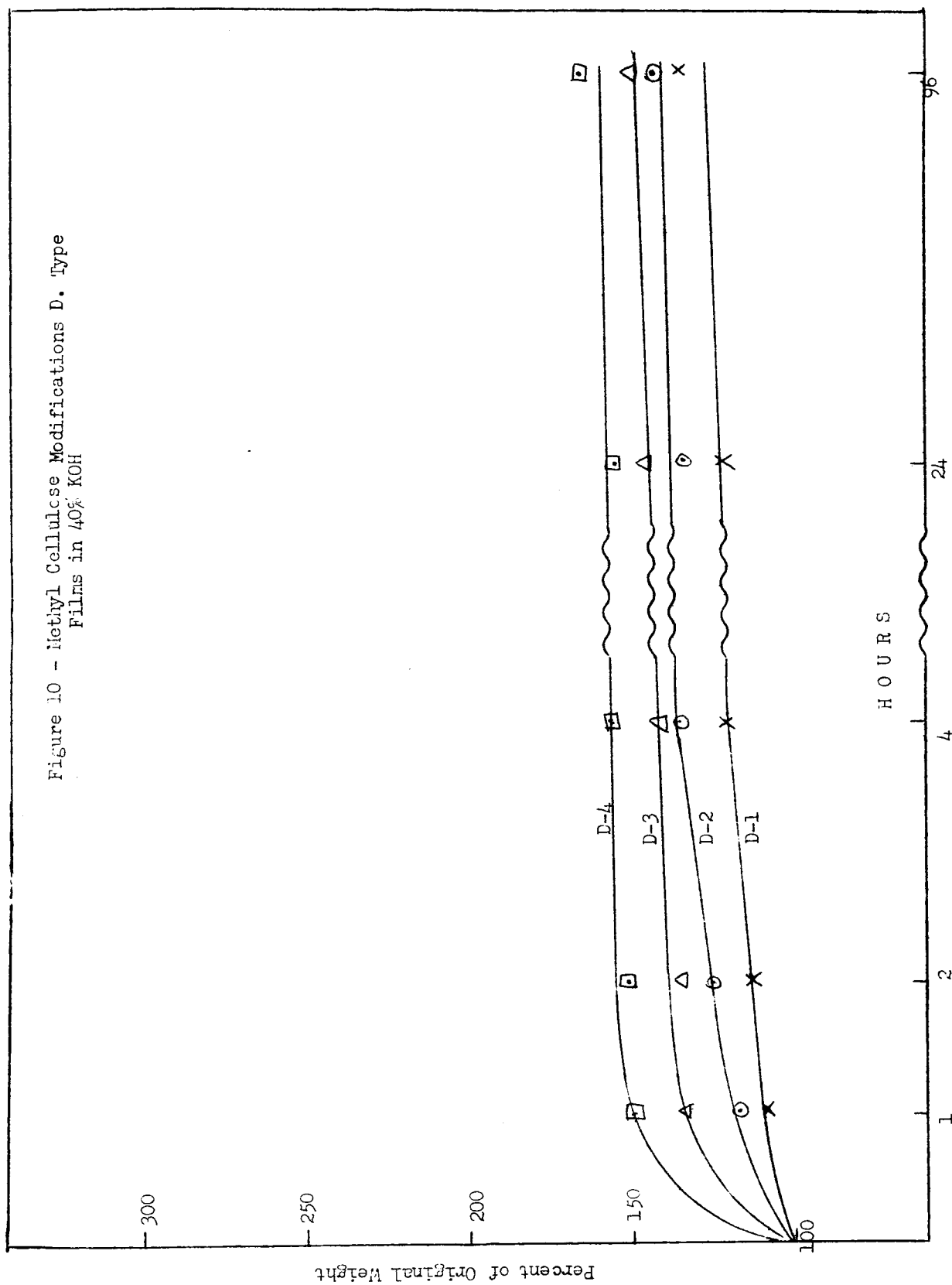


Figure 10 - Methyl Cellulose Modifications D. Type
Films in 40% KOH



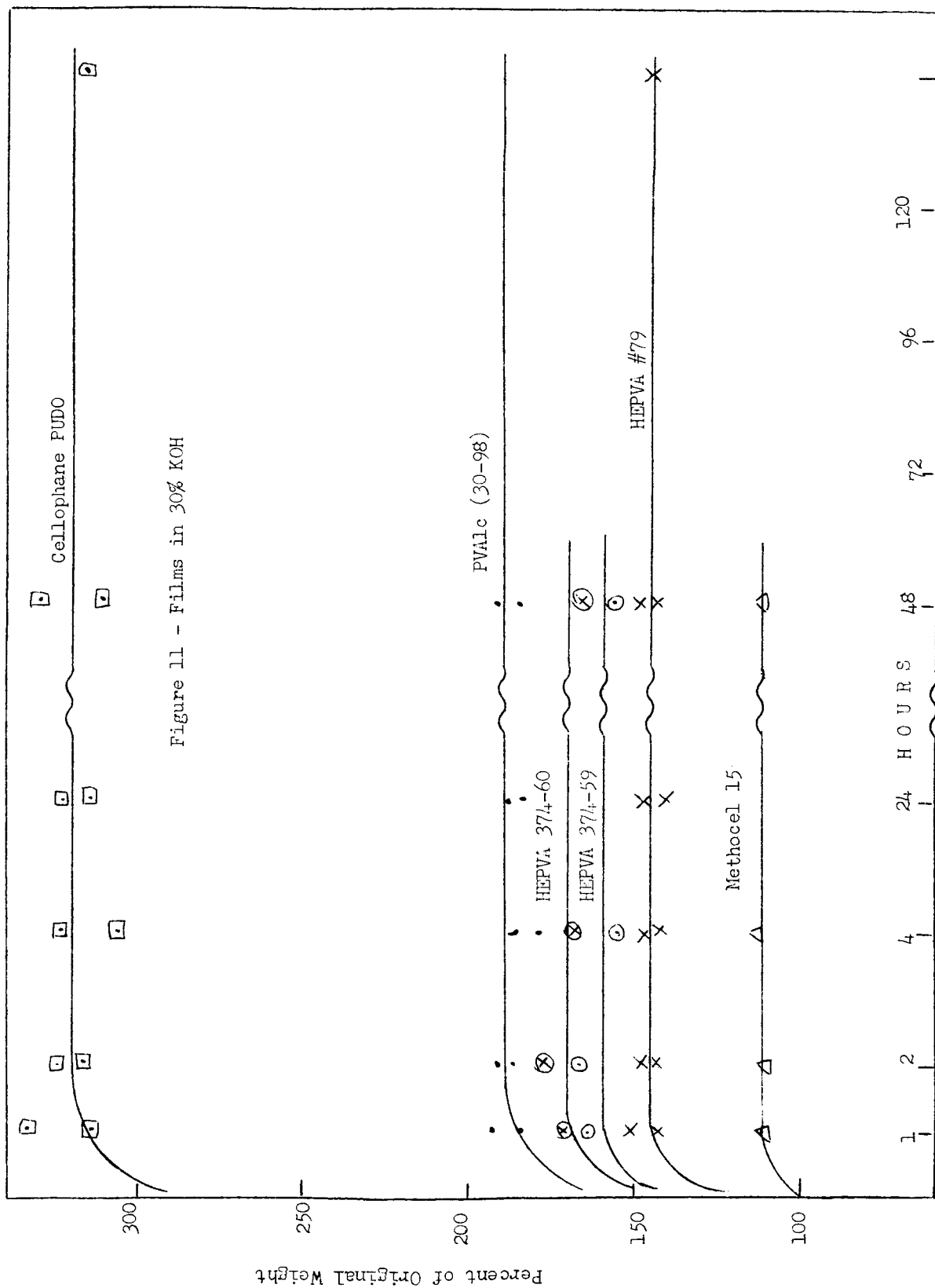


Figure 12 - Films in 40% KOH

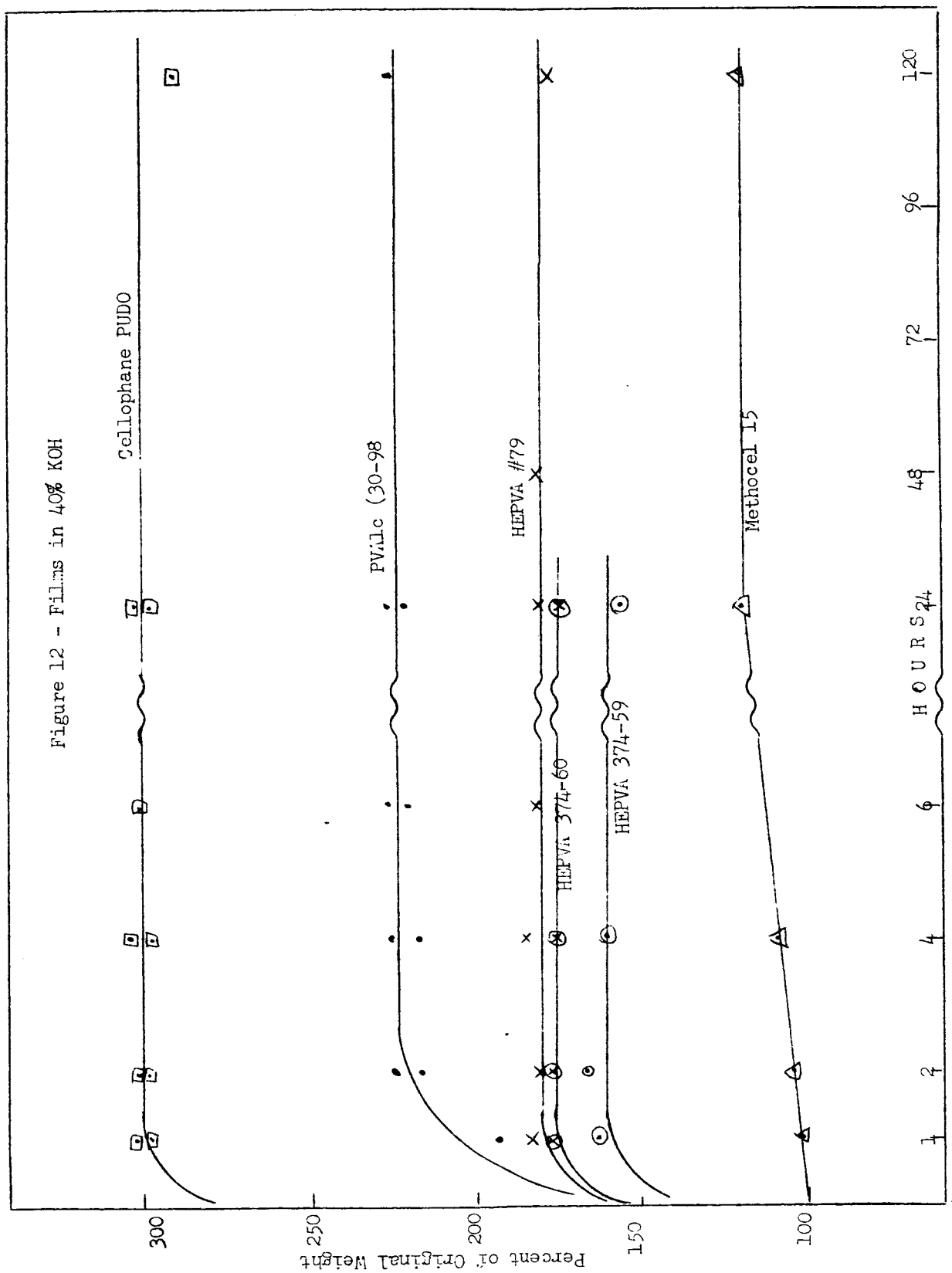
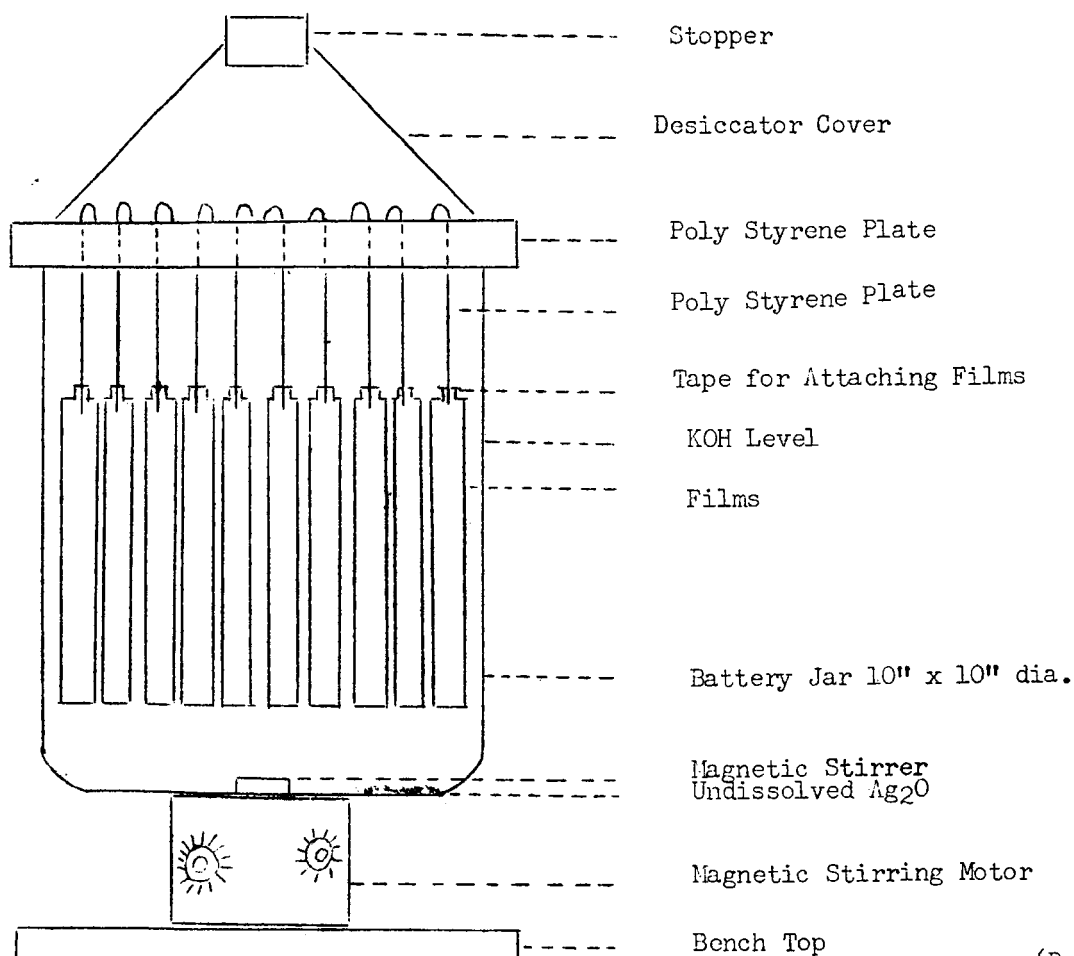
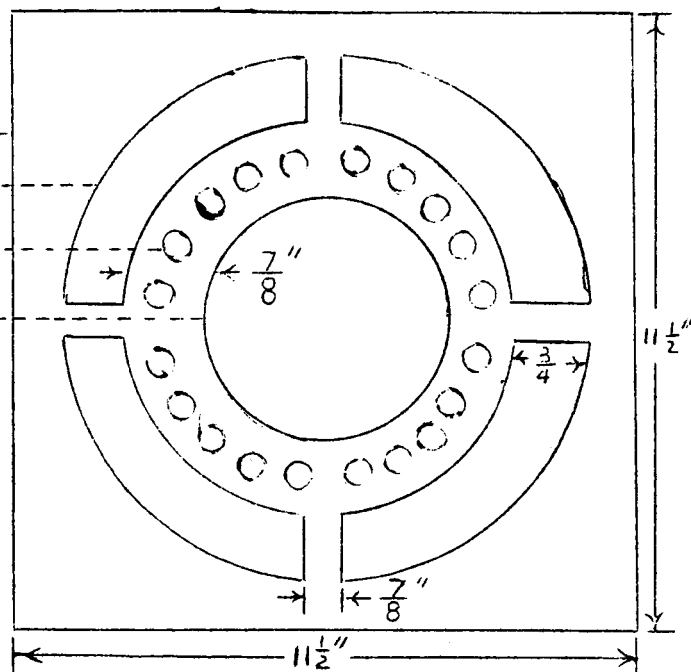


Figure 13 Oxidation Apparatus
Polystyrene Plate for
Suspending Films in
KOH solution

Cut-Away sections

Hole for Insulated Copper Wire

Cut-Away Center Section



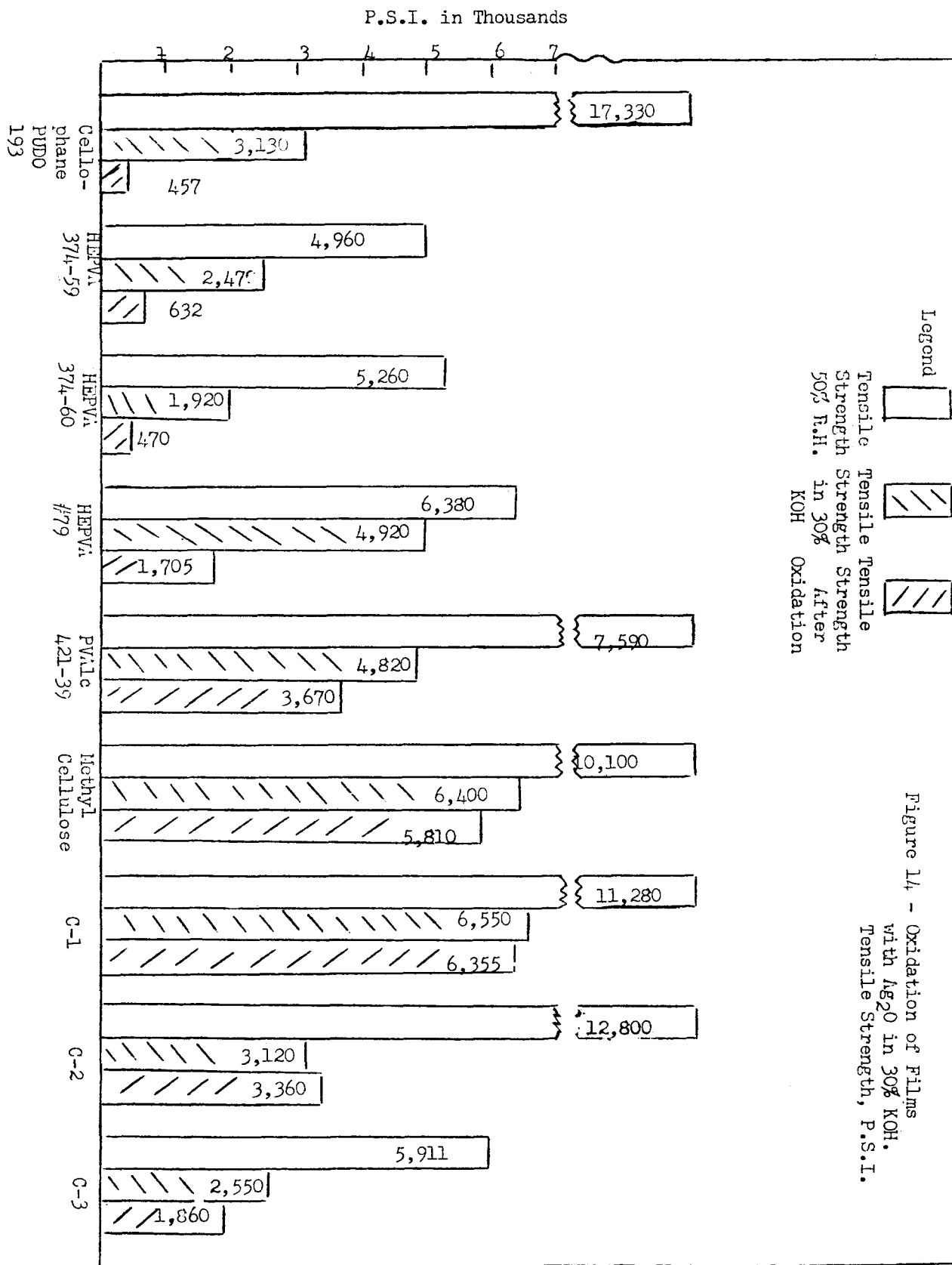


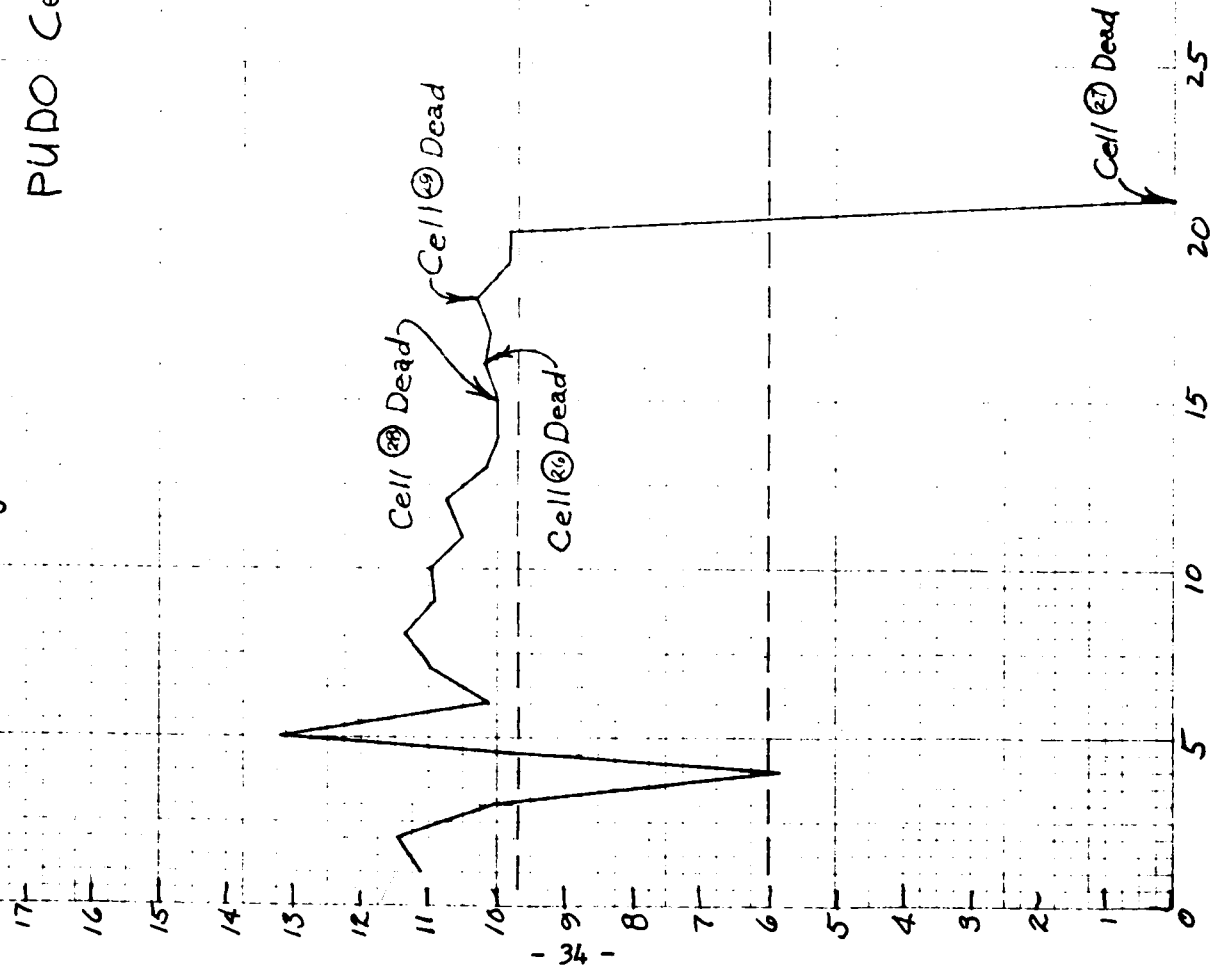
Figure 14 - Oxidation of Films with Ag₂O in 30% KOH. Tensile Strength, P.S.I.

Figure 15

Construction Type VII-13

Cycling Data

PUDO Cellophane



Design Capacity

Cycling Regime
Terminal Capacity

Figure 16 Construction Type X-13 Cycling Data

HEPVA 374-60

Cell ③ Dead

Cell ⑥ Dead

Design Capacity

Cycling Regime
Terminal Capacity

Cycle No.

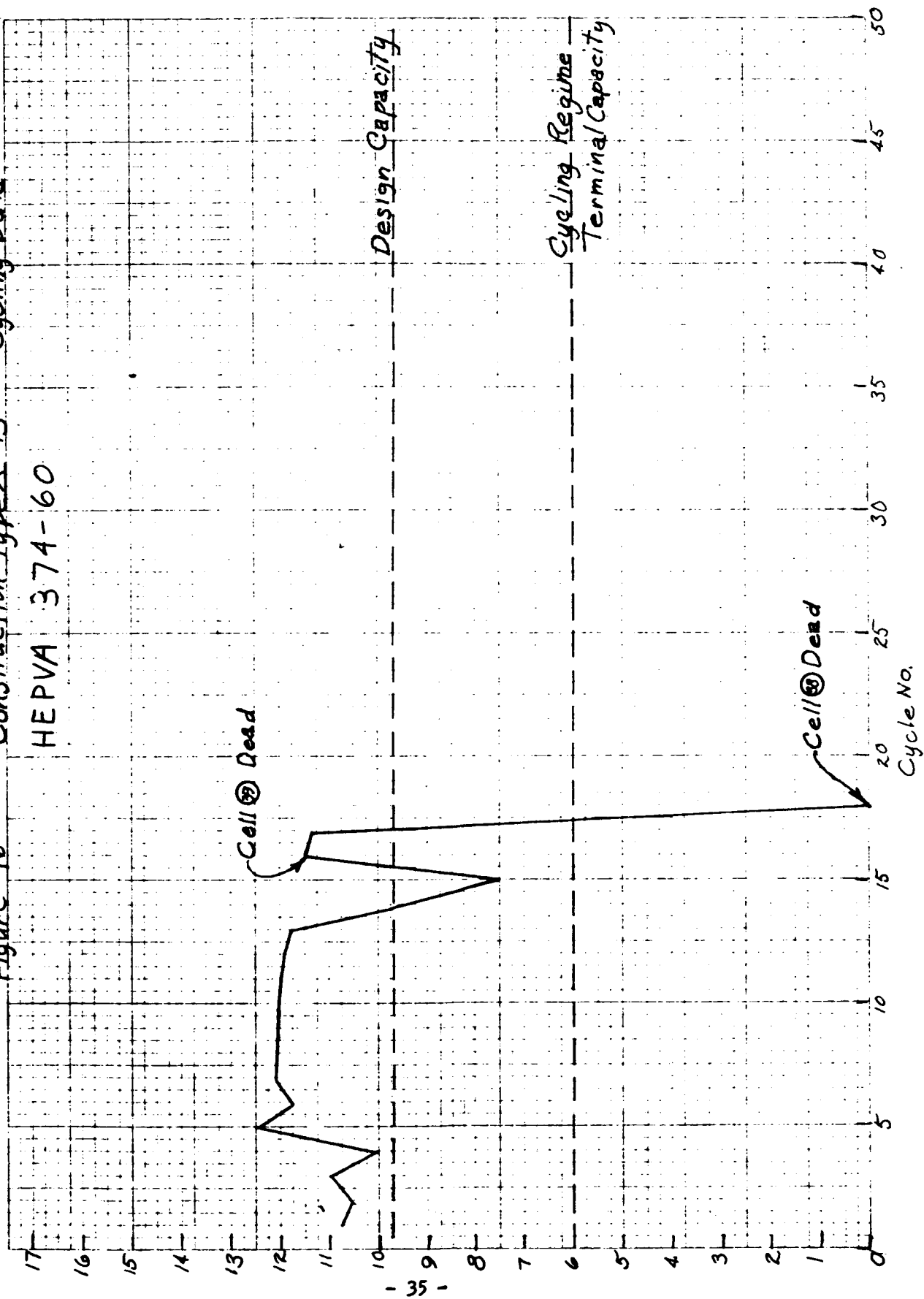


Figure 17

Construction Type XIII - 13

Cycling Data

Methyl Cellulose 389-104

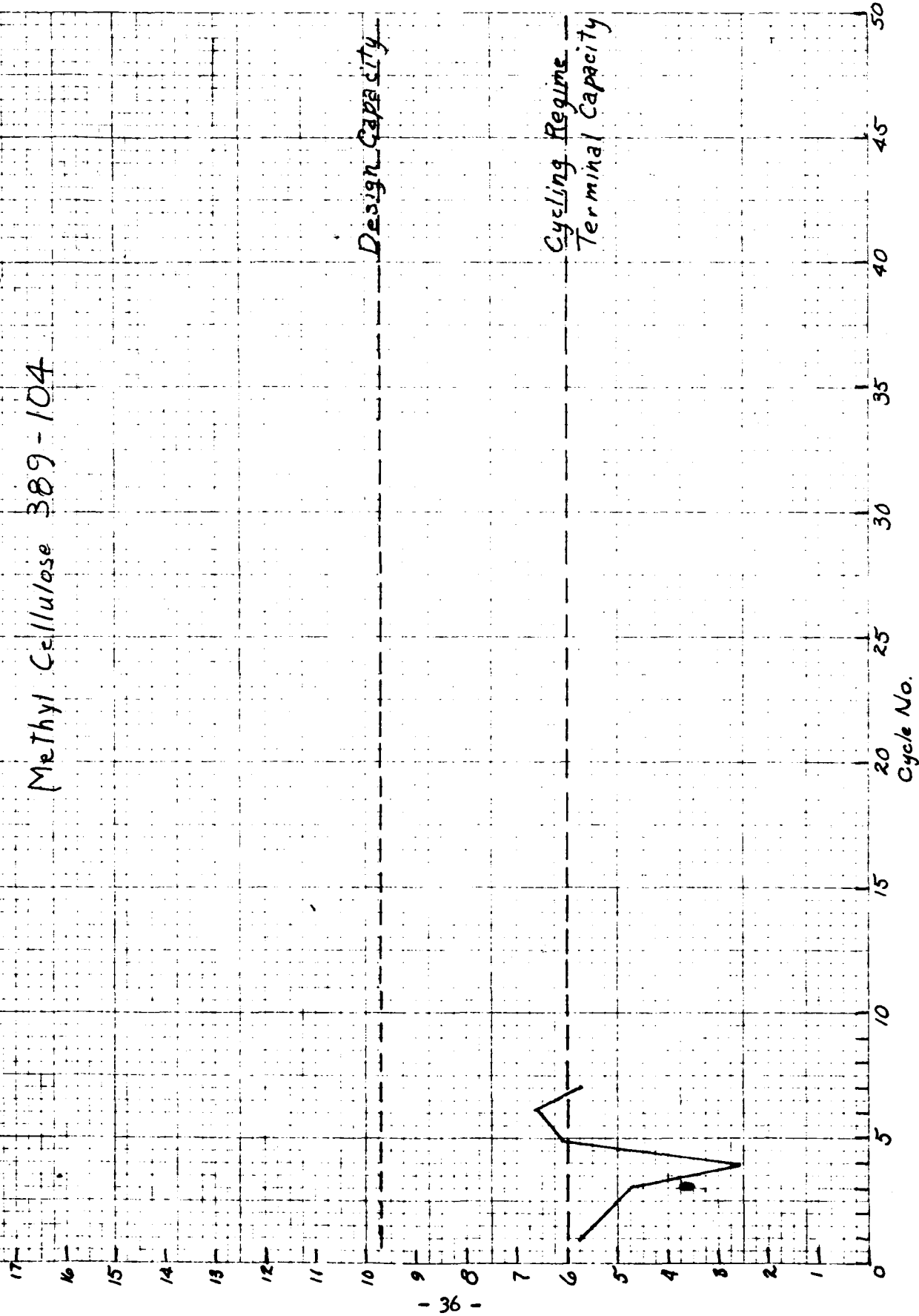


Figure 18 Construction Type VII, Typical Dischg. Curves

PUDO Cellophane

SZ-134510-A6

Dischg. 3, 4, 5, 6, 7

() Dischg. rate amp.

() Current Density
amp/in² Cathode
plate area

Design Capacity, 9.65 A.H

Discharge Capacity, A.H.

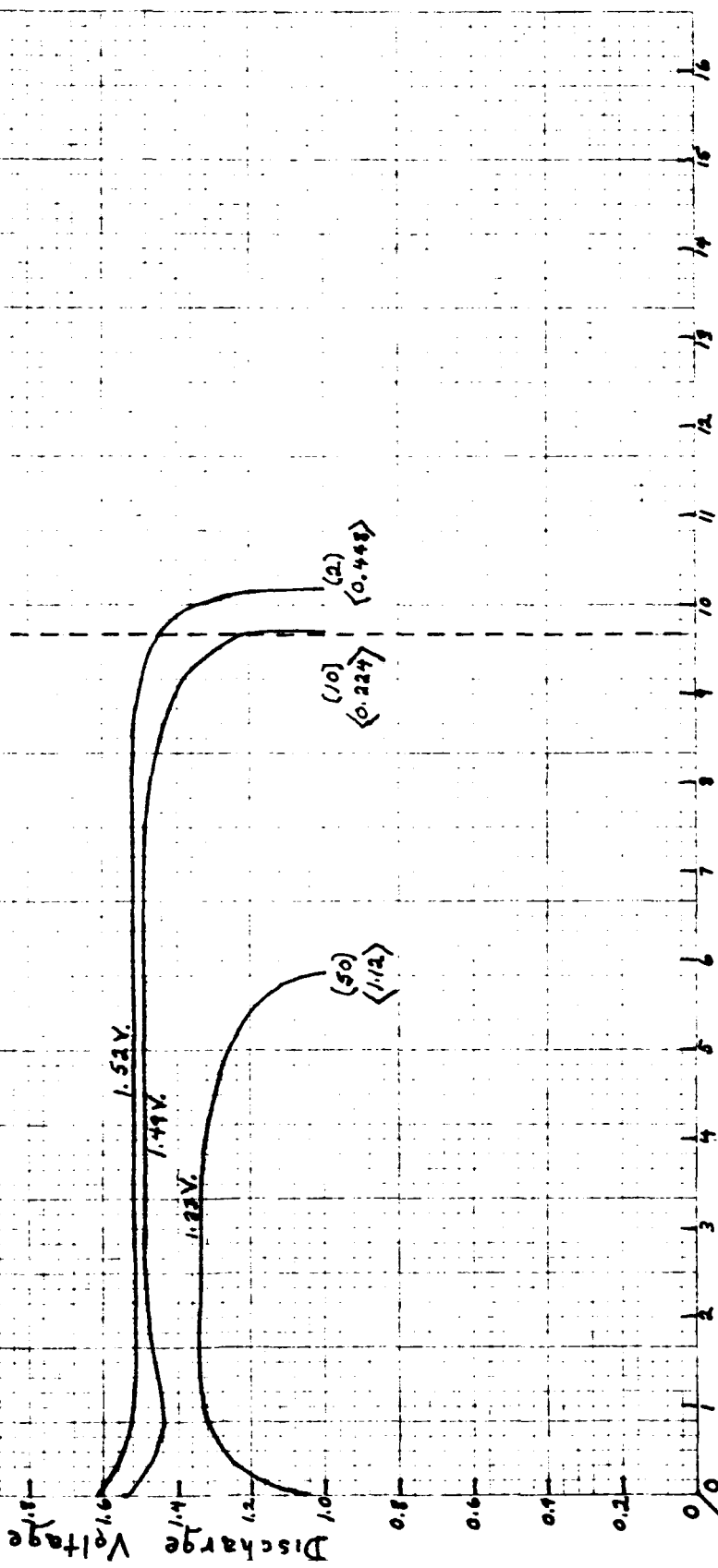


Figure 19 Construction Type X Typical Dischg Curves

HEPVA 374-60

SZ-134410-28

Dischg. 3.417

() Dischg rate amp

() Current Density
amp/in² Cathode
plate area.

Design Capacity, 9.65 A.H.

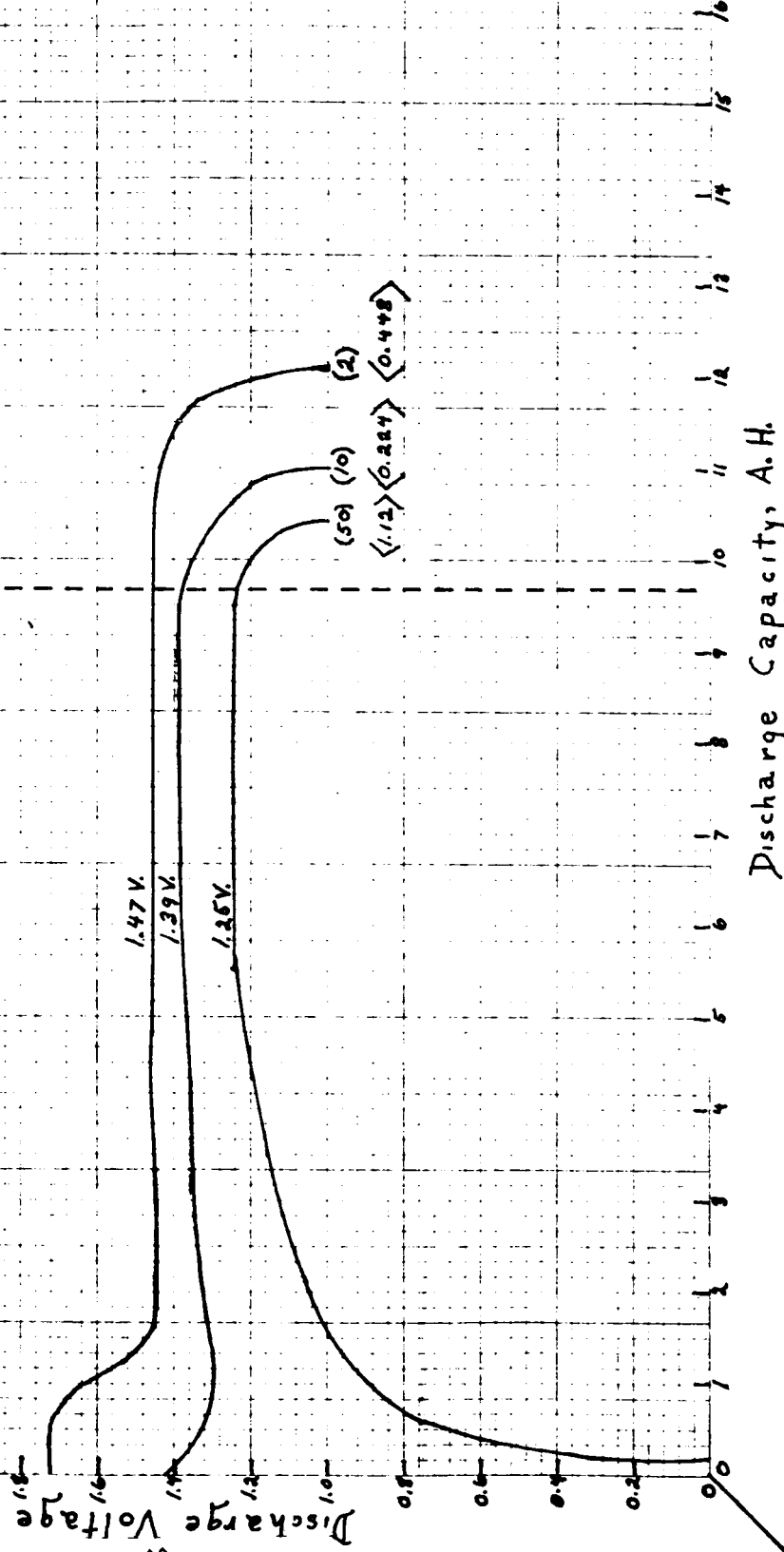


Figure 20 Construction Type XIII Typical Dischg. Curves

Methyl Cellulose 389-104

SZ-1134E10-76
Dischg. 3.487
(1) Dischg. rate amp
(2) Current Density
amp/in² Cathode
plate area

Design Capacity, 9.65 A.H.

